AIR FORCE OFFICE of SCIENTIFIC RESEARCH [AFOSR]
Manager of the Basic Research Investment for the Air Force

Research HIGHLIGHTS

SEP OCT 02

Breakthrough Optical Technology – Optical Coherence Tomography

An Air Force Office of Scientific Research-sponsored scientist, Dr. James Fujimoto, is the inventor and leading researcher of a new optical imaging tool that could have a profound effect on how images are created for use in medical diagnostics, materials science and microscopy.

Fujimoto, a professor in the department of Engineering and Computer Science Research Laboratory of Electronics at the Massachusetts Institute of Technology in Cambridge, Mass., and his team of students and collaborators have found that Optical Coherence Tomography (OCT) can provide high-resolution, cross-sectional imaging similar to that of ultrasound, only it uses light instead of sound.

OCT, an emerging technology based on fiber optics, often uses a compact diode light source similar to those used in compact disc players. Thus, OCT technology can be robust, portable, low cost, and can be readily interfaced with optical fiber tech-niques to catheters, endoscopes, laparo-scopes and surgical probes. These attributes make it very attractive for medical and surgical diagnostics.

ABOVE: OCT is an emerging technology based on fiber optics and often uses a compact diode light source only millimeters in size.

Other advantages for using OCT in medical diagnostics are:

- Provides images of tissue structure at the micron scale in situ and in real time;
- Functions as a type of optical biopsy, unlike the conventional histopathology that requires removal of tissue specimens to process for microscopic examination;
- Can be used where standard excisional biopsy is hazardous or impossible, possibly reducing sampling errors;
- Enables surgical guidance;
- Enables imaging of organ systems inside the body;
- Image resolutions are one to two orders above conventional ultrasound.

Ultrasound technology was most commonly used by health-care professionals to produce images for diagnosis. According to Fujimoto, ultrasound imaging technology uses sound waves, which travel into the material or tissue and is reflected or back-scattered from internal structures having different acoustic properties. The frequency of the sound wave determines the image resolution, with higher frequencies yielding higher resolutions.

Unfortunately, there are shortfalls to ultrasound technology. Primarily, the

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Examples of the use of OCT Technology:

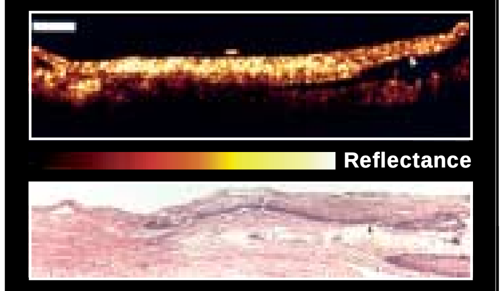

Figure 1: OCT image and histological section from a heavily calcified human aorta.

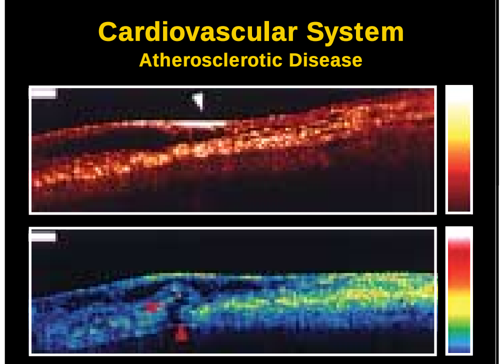

Figure 2: An OCT image determines in vitro the internal atherosclerotic plaque structure on a micron scale.

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sound wave loses strength as it travels. Also, there must be physical contact between the instruments and the tissue being examined. Another shortfall is that in higher frequencies, the depth level of the image is reduced.

Optical Coherence Tomography makes up for these short falls. In OCT, the echo time delay and intensity of back-scattered or back-reflected light is measured from the internal microstructure in materials or tissues. OCT produces images that are two- or three-dimensional data sets representing differences in optical back-scattering.

Examples of the use of OCT Technology:

Early Zebrafish Development

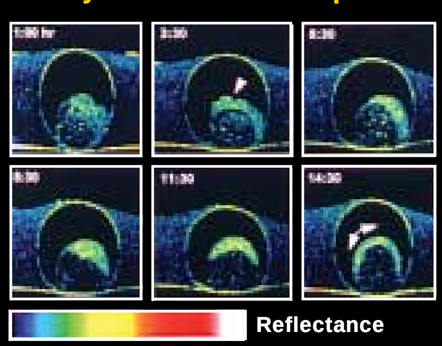


Figure 3: Early in vivo developmental changes in the Zebrafish show the potential of OCT to repeatedly sample and monitor changes over time.

Identification of Developmental Abnormalities

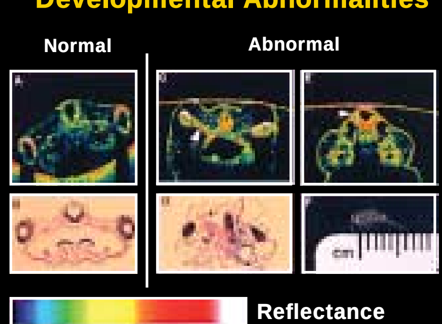


Figure 4: In vivo identification of the developing structure of a Xenopus. Illustrates the ability to recognize and follow, in vivo, developmental abnormalities and mutations from predetermined genetic manipulations.

"Whereas ultrasound pulse propagation and detection can be described in terms of time delays, the echo delay time of light returning to the OCT instrument from the specimen cannot be measured directly by electronic methods due to the high speeds associated with the propagation of light," stated Dr. Stephen Boppart, a former member of Fujimoto's team, now a professor at the University of Illinois. "Therefore, a technique known as Michelson interferometry is employed, which uses a reference and a sample arm."

With Michelson interferometry, light is split by a fiber coupler with half sent to a reference arm and half sent to the sample arm. One of the fibers directs light to the tissue being imaged and the other fiber to a moving reference mirror. By using a low coherence length light source and measuring the interference between light back-scattered from the tissue and from the reference mirror, this distance and magnitude of optical scattering within the tissue can be measured with micrometer-scale precision.

A cross-sectional image is produced by scanning a light beam across the tissue, while the axial reflectance profiles at each transverse position are recorded by computer. The result is a two-dimensional representation of the optical back-scattering of the tissue's cross section which displays as a gray-scale or false-color image.

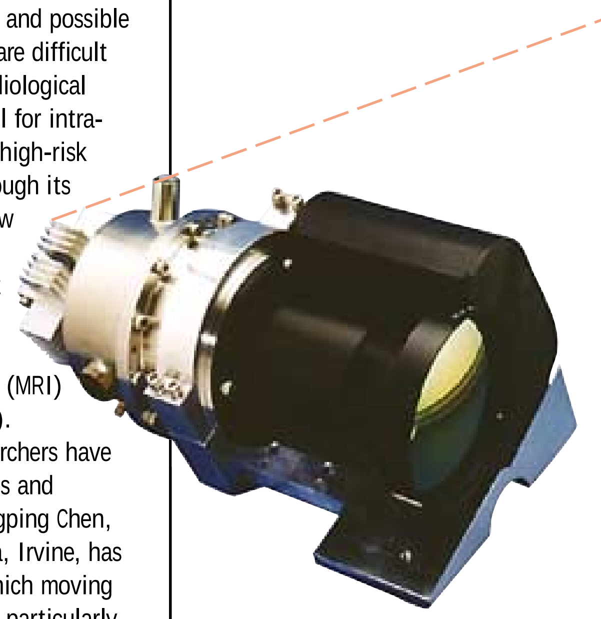
Opthalmology, the study of the eye, is an area of medical research that has benefited tremendously from this new technology, and the first area to have commercial instrumentation introduced.

Fujimoto stated that studies have been performed to investigate the feasibility of using OCT for the diagnosis and monitoring of retinal diseases, such as glaucoma, macular edema, macular hole, central serous chorioretinopathy, age-related macular degeneration, epiretinal membranes, optic disc pits and choroidal tumors. Since OCT can be performed in real time, research also is being done to measure dynamic responses of the retina to include retinal laser injury.

A particularly hopeful focus of research for OCT includes the diagnosis and monitoring of diseases such as glaucoma and macular edema linked to diabetic retinopathy. Because it can provide quantitative information regarding the disease's progression, Fujimoto contends that OCT has the potential to detect and diagnose early stages of the disease before physical symptoms and irreversible loss of vision occurs.

Another promising medical area of research to use OCT technology is in vascular pathology, the study of how fluids, such as blood, travel through the body.

It has been shown that most heart attacks result from the rupture of weakened coronary artery walls due to cholesterol-laden plaque, followed by a sequence of biochemical reactions. This rupture could result in thrombosis, vessel occlusion, and possible death. Because these lesions are difficult to detect by conventional radiological techniques, OCT can be useful for intra-coronary imaging to identify high-risk atherosclerotic plaques. Although its penetration is limited to a few millimeters, the resolution corresponds to an improvement of over 25-times that of high-frequency ultrasound, Magnetic Resonance Imaging (MRI) or Computer Tomography (CT).

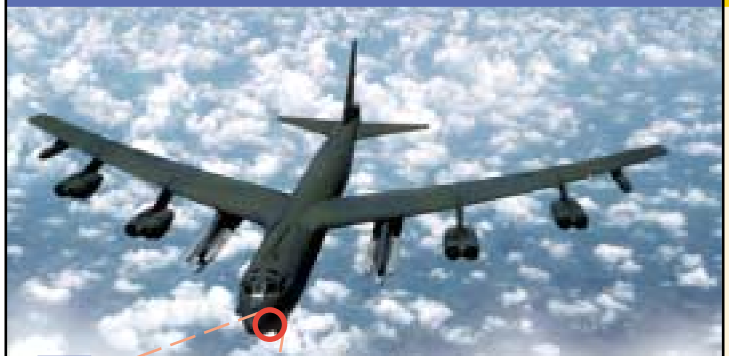


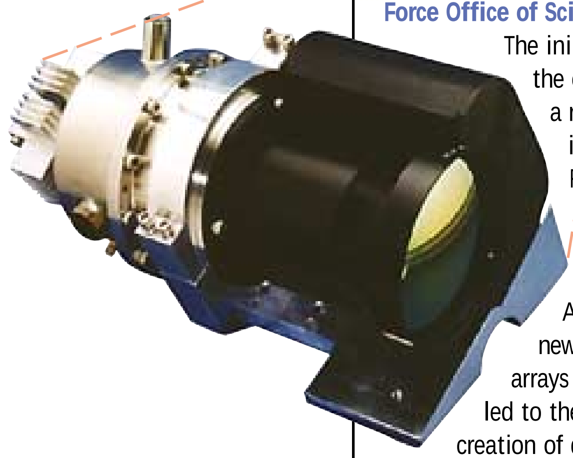
Other AFOSR-funded researchers have developed valuable extensions and applications of OCT. Dr. Zhongping Chen, of the University of California, Irvine, has developed Doppler OCT, in which moving surfaces are observed. This is particularly valuable for studying blood vessel function, and fluid flow, generally, in small structures. Dr. Johannes de Boer, of Massachusetts General Hospital (MGH), has developed polarization sensitive OCT, and applied it to diagnosing burns, to guide appropriate treatment. Drs. Brett Bouma and Guillermo Tierney at MGH, both former members of the Fujimoto group, have developed very portable, high performance OCT systems for clinical diagnostic studies. Over 100 patients have already been imaged, and major clinical investigations are ongoing in the fields of gastroenterology, dermatology, cardiology, urology, orthopedics, gynecology, and otolaryngology.

OCT is a very promising new optical technology with far reaching potential. Dr. James Fujimoto and the other researchers mentioned above are sponsored by AFOSR's Physics and Electronics directorate.

Dr. Howard Schlossberg
AFOSR/NE

AFOSR Support of Infrared Detector Research Pays Off





Today's fleet of Air Force B-52s are significantly better able to navigate and pinpoint targets at night thanks to infrared sensors developed through funding by the Air Force Office of Scientific Research.

The initial work toward infrared sensors began in the early 1970s when the Air Force established a requirement to "reduce the cost of infrared imaging." At the time, the Air Force Cambridge Research Laboratory (now the Air Force Research Laboratory's Sensors Directorate at Hanscom AFB, Mass.) was investigating photoemission physics in silicon-based Schottky barrier photodiodes. As a result, a patent was generated to define a new way to use this physics for infrared focal plane arrays (FPAs) on high quality silicon substrates. That led to the study of photoemission and the subsequent creation of discrete platinum silicide (PtSi) Schottky barrier detector devices at the Air Force Research Lab. Small PtSi detector arrays were made at Hanscom and the technology was transferred to silicon manufacturers who could scale up the process and produce large staring infrared FPAs.

During the 1980s the AFOSR's research emphasis shifted to understanding the fundamental limitations of staring infrared sensing and techniques for processing large infrared images. Large images resulted from the cameras the research lab created from the large FPAs that were being produced in AFRL's Advanced Development programs. By the end of the '80s, the AFRL approached Air Combat Command (ACC) leaders about retrofitting the B-52 scanning FLIR (Forward Looking Infrared) with a staring, PtSi infrared sensor. The AFRL, in collaboration with contractors, had developed 300,000 pixel FPAs, the largest infrared arrays in the world at that time. Engineering tests of a Hanscom-built, prototype PtSi camera convinced ACC leaders that this new sensor would give the B-52 fleet a superior infrared capability for night navigation and targeting.

By the end of the 1990s all had been retrofitted with the new sensor; to include the purchase of a substantial number of logistical spares.

AFOSR's foresight in understanding the importance of this research and continuing its support, gave the Air Force a dramatically improved operational infrared capability.

Dr. Gerald Witt
AFOSR/NE

ODU Grant

The Air Force Office of Scientific Research presented Old Dominion University's Dr. Karl H. Schoenbach a $5 million, five-year Multidisciplinary Research Initiative (MURI) grant in a ceremony on Aug. 19. The grant will fund his work in bioelectrics, which holds possibilities for rapid wound healing and perhaps a new non-traumatic treatment for cancer.

Dr. Schoenbach, an eminent scholar of electrical and computer engineering at the university, will serve as the grant's principal investigator with Old Dominion University as the lead institution of a seven-university consortium.

Working with Eastern Virginia Medical School's Dr. Stephen Beebe, Schoenbach discovered the ability of ultra-short pulses of high-intensity electric fields to kill tumor cells, reduce the number of fat cells, and remodel bone and cartilage. With the MURI grant, he will expand his research to explore the effect of electromagnetic fields on DNA and proteins. This research will help scientists to determine the parameters that promote cell growth and/or prevent the degeneration of diseased or injured cells, tissues and organs. Schoenbach's research also should help the military understand how the use of radiation affects military personnel.

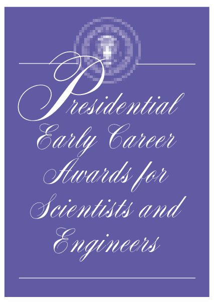
The MURI program supports basic science and engineering research of critical importance to national defense. The program is focused on multidisciplinary research efforts that intersect more than one traditional science and engineering discipline. By supporting multidisciplinary teams, the program is complementary to other DoD programs that support university research through single-investigator awards.

"We owe a lot to the Air Force Office of Scientific Research," said Schoenbach. "They are the main agency that has helped us get to where we are today."

Dr. Schoenbach is funded by AFOSR's Physics and Electronics directorate.

Dr. Robert Barker (right) presents Dr. Karl Schoenbach and Old Dominion University with a check for $5 million.

Citations of AFOSR PECASE Winners



Two Air Force Office of Scientific Research-funded engineers were recently awarded the highest honor given scientists by the U.S. government, the Presidential Early Career Award for Science and Engineering, or PECASE. Dr. Raffaello D'Andrea, a Cornell University mechanical and aerospace engineering professor, and **Dr. Scott Robert Manalis,** a professor of Media Arts & Science and Bioengineering at Massachusetts Institute of Technology, were among a select group of scientists and engineers honored in a White House ceremony, June 26. PECASE was established in 1996 by President Bill Clinton to "nurture and support" America's finest young scientific minds.

Dr. D'Andrea was singled out as a recognized leader in the area of theoretical and experimental control systems engineering, a field that deals with the problem of analyzing and designing feedback system that exhibits desirable performance characteristics in the presence of inevitable modeling errors. D'Andrea's research has contributed to advances in the robust control of feedback systems with applications to the cooperative control of distributed autonomous vehicles in dynamic, uncertain, adversarial environments.

Dr. Raffaello D'Andrea

Control systems are everywhere – in cruise controls in cars, CD players, and disk drives. They are also in power plants and in high-performance vehicles such as airplanes, D'Andrea explained.

D'Andrea's work with this critical technology can be used in dealing with flight and jet engine control problems found in the military and civilian aviation communities.

Dr. Manalis received recognition for making significant contributions in the development of innovative scanning probe nanotechnologies that are leading to new microelectronic devices, and to the detection of structure and structural changes in DNA and proteins. His recent research has focused on the development of unique surface modification strategies for nanoscale sensors that will enable the detection of biological components at levels down to single molecules.

Photo: Webb Chappell, © Webb Chappell

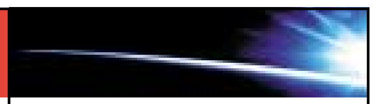
Dr. Scott Robert Manalis

Manalis said he hopes to create revolutionary new tools for advancing molecular biology. He wants to get direct information on DNA or protein molecules by binding them to, say, silicon transistors or tiny cantilevers.

These awards embody the high priority placed by the government on maintaining the leadership position of the United States in science by producing outstanding scientists and engineers and nurturing their continued development.

AFOSR has moved!

The Air Force Office of Scientific Research has relocated the Arlington, Va. office. Please note that our address has changed to 375 N Randolph St. Suite 325 Arlington, VA 22203-1954.



Research Highlights

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AFOSR would like to thank Drs. Howard Schlossberg, Robert Barker, and Gerald Witt for their assistance in making this issue possible.

Research Highlights is published every two months by the Air Force Office of Scientific Research. This newsletter provides brief descriptions of AFOSR basic research activities including topics such as research accomplishments, examples of technology transitions and technology transfer, notable peer recognition awards and honors, and other research program achievements. The purpose is to provide Air Force, DoD, government, industry and university communities with brief accounts to illustrate AFOSR support of the Air Force mission. *Research Highlights* is available on-line at:

http://www.afosr.af.mil

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Correction

In the July/August 2002 issue of *Research Highlights*, we inadvertently omitted Dr. Gernot Pomrenke of AFOSR's Physics and Electronics Directorate as jointly funding the research on the article "Designing Semiconductor Active Materials Prior to Wafer Growth and Device Fabrication." The *Research Highlights'* staff would like to apologize for the omission.

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